ZnO as a New Catalyst for *N*-Formylation of Amines in Solvent-Free Conditions

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Table of Content:

Chemicals were purchased from Fluka, Merck, B. D. H. and Aldrich Chemical Companies. Progress of the reactions was followed by TLC using silica gel polygrams SIL G/UV 254 plates or by GC using a Shimadzu gas chromatograph GC-14A, equipped with a flame ionization detector and a 3 meters length glass column packed with DC-200 stationary phase and nitrogen as the carrier gas. IR spectra were recorded on a Perkins Elmer 781 and on Impact 400 D Nickolet FTIR spectrophotometers. NMR spectra were recorded on a Bruker DPX 250 MHz instrument.

General Procedure: To a mixture of HCO_2H (3 mmol, 0.11 mL) and ZnO (0.5 mmol, 0.04 g) an amine (1 mmol) was added and then the reaction mixture was heated in an oil bath at 70 ^{o}C and stirred with a magnetic stirrer. The progress of the reaction was monitored by TLC. After the reaction was complete, CH_2Cl_2 or EtOAc was added to the reaction mixture and ZnO was removed by filtration. The organic solvent was then washed with H2O (2x10 mL), saturated solution of $NaHCO_3$, and dried over anhydrous Na_2SO_4. After removal of the solvent, the pure product was obtained. This was further purified by recrystallization with suitable solvent (ether or $CHCl_3$). The structure of the products was confirmed by ^{1}H NMR, IR and comparison with authentic samples obtained commercially or prepared by reported methods.

N-Phenyl formamide (**1**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 9.33 (brs, 1H, *trans*), 8.7 (brs, 1H *cis*), 8.65 (d, 1H, *J*=11.28, *trans*), 8.12 (s, 1H, *cis*), 6.99-7.58 (m, 5H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 117.5-131.0, 137.0, 161.7, 164.9.

N-(3-Methylphenyl) formamide (**2**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 9.19 (brs, 1H, *trans*), 8.64 (d, 1H, *J*=11.39, *trans*), 8.46 (brs, 1H *cis*), 8.30 (s, 1H, *cis*), 6.90-7.46 (m, 4H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 13.0, 119.7, 121.6, 121.9, 127.3, 137.9, 138.5, 168.5.

N-(2-Chlorophenyl) formamide (**3**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.59 (d, 1H, *trans*), 8.41 (s, 1H *cis*), 8.27 (d, 1H, *J*=1.15, *trans*), 7.87 (brs, 1H, *cis*), 6.80-7.30 (m, 4H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 118.8, 122.0, 125.1, 127.7, 129.1, 130.3, 133.7, 159.1, 161.7.

N-(3-Chlorophenyl) formamide (**4**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.98 (brs, 1H, *trans*), 8.59 (d, 1H, *J*=11.19, *trans*), 8.26 (s, 1H, *cis*), 8.02 (brs, 1H *cis*), 7.03-7.57 (m, 4H, Ar-H)); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 118.8-132.1, 161.2, 164.3..

N-(2-Bromophenyl) formamide (**5**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.78 (d, 1H, *trans*), 8.38 (s, 1H *cis*), 8.21 (d, 1H, *J*=1.25, *trans*), 7.94 (brs, 1H, *cis*), 6.65-7.44 (m, 4H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 113.3, 119.5, 125.7, 128.3, 132.4, 134.8, 159.4, 162.0.

N-(3-Bromophenyl) formamide (**6**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 9.12 (brs, 1H, *trans*), 8.66 (d, 1H, *J*=11.2, *trans*), 8.50 (brs, 1H *cis*), 8.34 (s, 1H, *cis*), 7.02-7.81 (m, 4H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 113.1, 119.2, 122.3, 125.6, 128.4, 132.3, 133.4, 134.8, 159.0, 161.7.

N-(4-Bromophenyl) formamide (**7**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 9.21 (brs, 1H, *trans*), 8.46 (d, 1H, *J*=11.32, *trans*), 8.23 (s, 1H, *cis*), 8.15 (brs, 1H *cis*), 7.39-7.45 (m, 2H, Ar-H), 6.93-6.99 (m, 2H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 115.4, 115.8, 116.3, 116.6, 120.9, 121.1, 132.7, 158.4, 163.3.

N-(4-Flourophenyl) formamide (**8**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 9.06 (brs, 1H, *trans*), 8.46 (d, 1H, *J*=11.32, *trans*), 8.23 (s, 1H, *cis*), 8.15 (brs, 1H *cis*), 7.39-7.45 (m, 2H, Ar-H), 6.93-6.99 (m, 2H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 115.4, 115.8, 116.3, 116.6, 120.9, 121.1, 132.7, 158.4, 163.3.

N-(2-Hydroxyphenyl) formamide (**9**): ^{1}H NMR (250 MHz, DMSO) δ 9.91 (brs, 1H, *trans*), 9.54 (s, 1H, OH), 8.92 (brs, 1H *cis*), 8.26 (s, 1H, *cis*), 7.98 (d, 1H, *J*=7.8, *trans*), 6.34-6.89 (m, 4H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 114.9, 119.5, 121.6, 124.4, 125.5, 146.6, 160.2.

N-(3-Hydroxyphenyl) formamide (**10**): ^{1}H NMR (250 MHz, DMSO) δ 10.02 (brs, 1H, *trans*), 9.97 (s, 1H, OH), 9.49 (s, 1H *cis*), 8.68 (d, 1H, *J*=11 *trans*), 8.19 (s, 1H, *cis*), 6.01-7.16 (m, 4H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 104.6, 108.3, 110.9, 129.6, 138.7, 159.8, 162.7.

N-(4-Hydroxyphenyl) formamide (**11**): ^{1}H NMR (250 MHz, DMSO) δ 10.05 (brs, 1H, *trans*), 9.22 (brs, 1H), 8.46 (d, 1H, *J*=11.2 *trans*), 8.13 (s, 1H, *cis*), 6.50-7.38 (m, 4H, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 115.1, 120.1, 153.4, 158.7, 162.5.

N-(2-Hydroxy-5-methylphenyl) formamide (**12**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.25 (s, 1H), 7.48 (brs, 1H), 6.48-7.04 (m, 3H, Ar-H), 3.72 (s, 1H), 2.26 (s, 3H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 20.4, 118.8, 122.2, 127.8, 130.3, 143.6, 156.8; *m/z* 151(M+).

N-(4-Acetylphenyl) formamide (**13**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.44 (s, 1H), 8.22 (brs, 1H), 7.94 (d, 2H, *J*= 1.82, Ar-H), 7.75 (d, 2H, *J*= 2.47, Ar-H), 2.53 (s, 3H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 16.0, 112.1, 117.1, 130.4, 130.7, 132.9, 141.5, 159.8, 162.3, 197.5; *m/z* 151(M+).

4-Formylamino benzoic acid (**14**): ^{1}H NMR (250 MHz, DMSO) δ 12.73 (brs, 1H), 10.66 (s, 1H), 8.32 (s, 1H), 7.84 (d, 2H, *J*= 6.95, Ar-H), 7.65 (d, 2H, *J*= 8.67, Ar-H)); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 116.8, 118.96, 126.01, 130.96, 142.57, 160.53, 167.29; *m/z* 165.1(M+).

N-(4-Nitrophenyl) formamide (**15**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 10.43 (brs, 1H), 8.31 (s, 1H), 7.97 (d, 2H, *J*= 8.75, Ar-H), 7.57 (d, 2H, *J*= 8.72, Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 112.1, 117.1, 129.7, 130.4, 132.9, 133.4, 141.5, 141.7, 159.8, 162.3.

N-(3-Nitrophenyl) formamide (**16**): ^{1}H NMR (250 MHz, DMSO) δ 10.67 (s, 2H,), 8.93, 10.47 (dd, 1H, *J*=8.8, 9.5), 8.60 (s, 1H), 8.38(s, 1H), 7.56-7.92 (m, 3H,Ar-H); ^{13}C NMR (62.9 MHz, DMSO) δ 111.4, 113.2, 122.9, 124.9, 130.1, 139.1, 147.8, 160.2, 162.6.

N-(2-Nitrophenyl) formamide (**17**): ^{1}H NMR (250 MHz, DMSO) δ 10.31 (brs, 1H), 8.92 (d, 1H, *J*=7.2), 8.59 (s, 1H), 8.11 (d, 1H, *J*= 1.45), 7.66 (m, 1H), 7.34-7.35 (m, 1H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 116.8, 118.8, 122.7, 123.9, 125.8, 136.0, 144.7, 159.6.

N-(2-cyanophenyl) formamide (**18**): ^{1}H NMR (250 MHz, DMSO) δ 9.84 (brs, 1H), 8.77 (d, 1H, *J*=7.2), 8.59 (s, 1H), 8.11 (d, 1H, *J*= 7.2), 7.66 (m, 1H), 7.34-7.35 (m, 1H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 116.3, 118.9, 121.7, 124.5, 132.4, 134.0, 159.7, 161.9.

N-(3-cyanophenyl) formamide (**19**): ^{1}H NMR (250 MHz, DMSO) δ 10.51 (s, 2H,), 8.84, 10.33 (dd, 1H, *J*=10.75, 10.6), 8.35 (s, 1H), 8.304 (s, 1H), 7.17-7.80 (m, 3H,Ar-H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 111.6, 118.5, 119.7, 122.0, 123.6, 130.2, 138.8, 160.1, 162.6.

N-(2-Fluorophenyl) formamide (**20**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.84 (s, 1H), 8.34 (s, 1H), 8.12 (d, 1H, *J*=8.2), 7.93 (brs, 1H), 6.80-7.58 (m, 4H, Ar-H)); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 121.6-134.0, 159.7, 162.6; *m/z* 189(M+).

N-(2-Pyridylmethylphenyl) formamide (**21**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 9.02 (s, 1H), 8.54 (s, 1H), 7.65-7.77 (m, 1H), 7.20-7.30 (m, 2H), 6.98 (brs, 1H), 4.61(s, 2H)); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 42.8, 122.1, 122.5, 136.9, 148.9, 159.7, 161.1; *m/z* 136(M+).

N-(6-Formylamino-2-Pyridyl) formamide (**22**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 9.20 (s, 2H), 8.17 (s, 2H), 7.63 (d, 2H, *J*=21.32), 7.26 (t, 1H, *J*=7.52); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 106.3, 140.8, 161.0, 162.5; *m/z* 165(M+).

N,*N*-Diphenyl formamide (**23**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.55 (s, 1H), 7.03-7.36 (m, 10H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 124.0-129.5, 140.9, 162.3.

N,*N*-Diisopropyl formamide (**24**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 6.80-6.90 (m, 1H), 4.09-4.23 (m, 1H), 3.73 (s, 1H), 1.18-1.42 (m, 12H) ; ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 24.0, 48.8, 169.9.

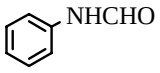
N-Butyl formamide (**25**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.54 (s, 1H), 5.77 (brs, 1H), 3.18-3.34 (m, 2H), 1.25-1.57(m, 4H), 0.939t, 3H, *J*=7.05) ; ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 13.5, 19.9, 31.5, 37.9, 161.2.

4-Morpholine carbaldehydede (**26**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.00 (s, 1H), 3.31-3.765 (m, 8H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 40.6, 66.4, 163.5.

N-(2-Hydroxyethyl) formamide (**27**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.18(s, 1H, *trans*), 8.07 (s, 1H, *cis*), 6.81(brs, 1H, *trans*) 6.54 (brs, 1H, *cis*), 4.70 (brs, 1H, OH), 3.21-4.30 (m, 4H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 40.9, 61.8, 161.8; *m/z* 89 (M+).

Ethyl-2-formylamino-2-phenylacetate (**28**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.15(s, 1H), 8.10 (s, 1H), 7.71-7.30 (m, 5H), 4.31(t, 1H), 4.04-4.14 (m, 2H), 1.11-1.28 (m, 3H); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 14.0, 60.9, 62.2, 127.1, 128.6, 129.4, 134.2, 161.0, 164.7; *m/z* 207 (M+).

3.11-Dioxo-3,4,5,6,9,10,11,12-octahydro-*2H*-1,13,4,7,10-benzodioxatriazacyclopentadecine-7(*8H*)-carbaldehyde (**29**): ^{1}H NMR (250 MHz, $CDCl_3$) δ 8.44(s, 1H), 8.08 (brs, 1H), 6.95-7.08 (m, 5H), 4.58(s, 4H), 8.89 (t, 4H, *J*=5.62), 3.54 (t, 4H, *J*=4.23); ^{13}C NMR (62.9 MHz, $CDCl_3$) δ 37.0, 49.1,70.7, 117.1, 123.7, 165.1, 168.6, 168.8; *m/z* 321(M+).



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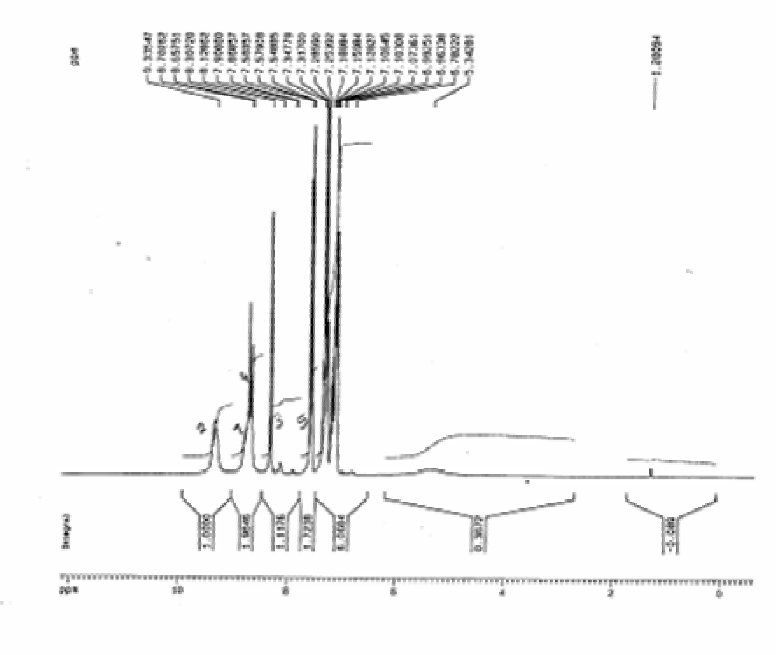

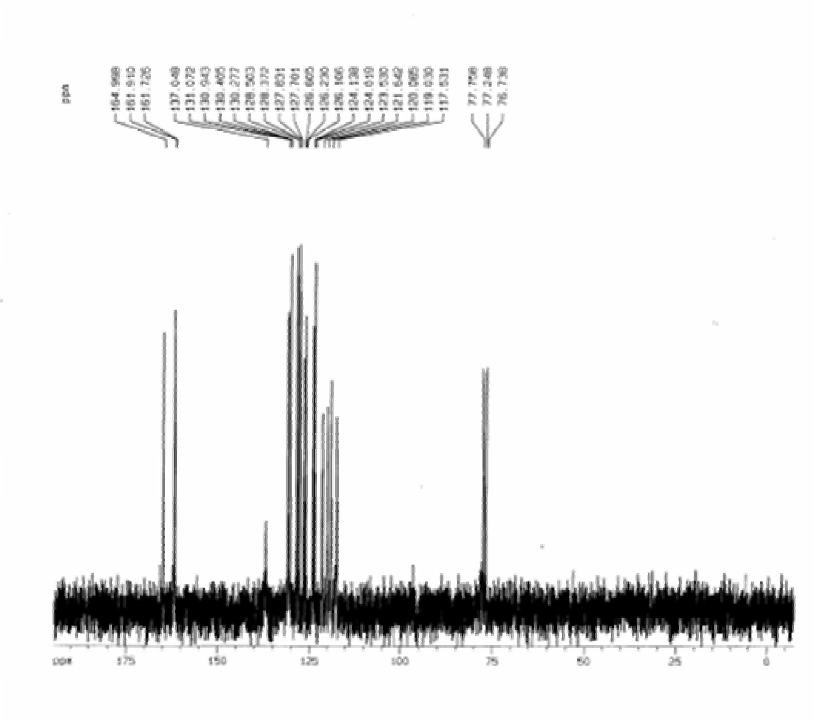

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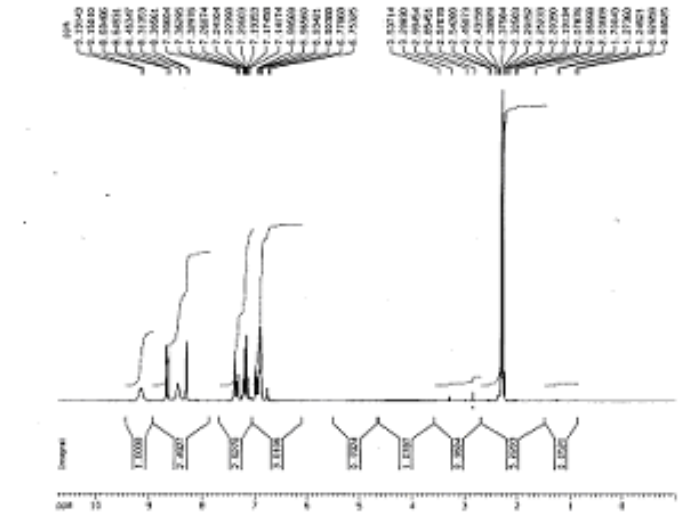

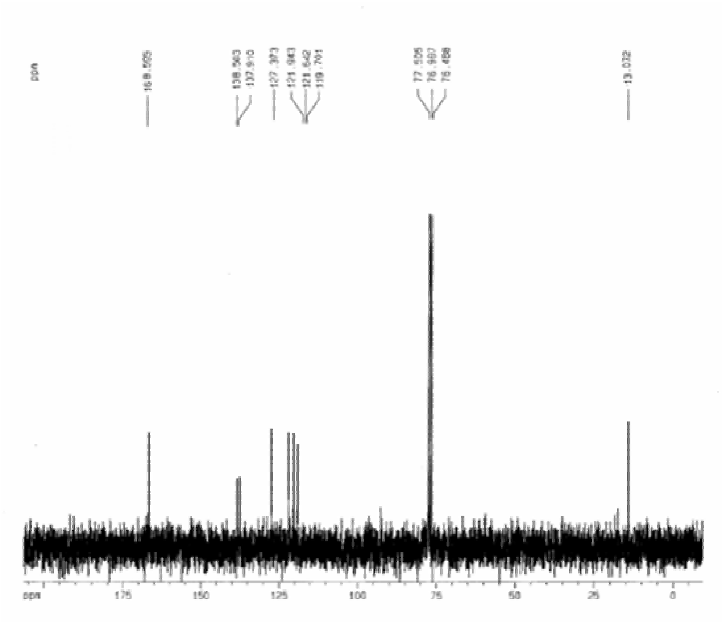

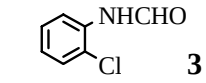

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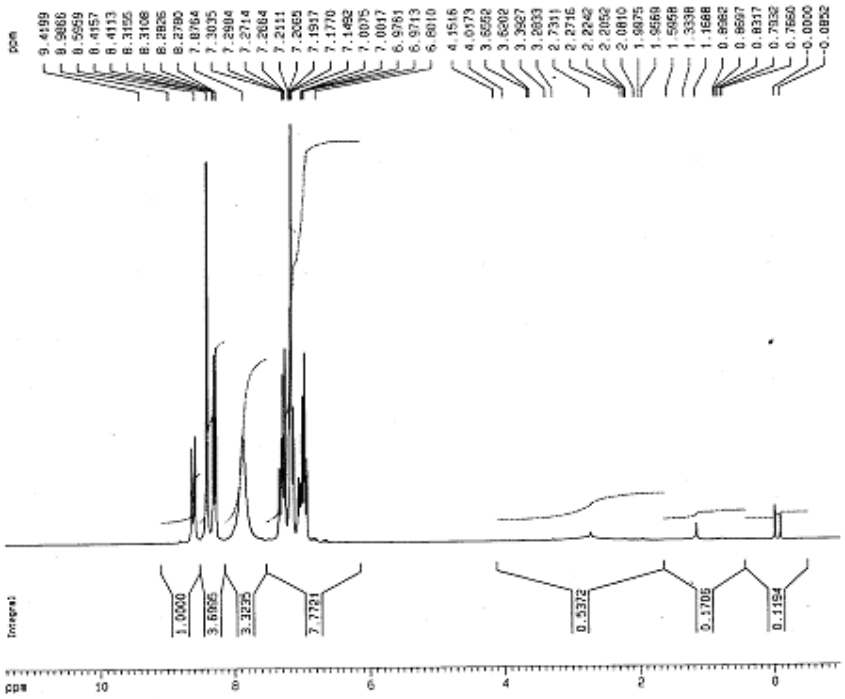

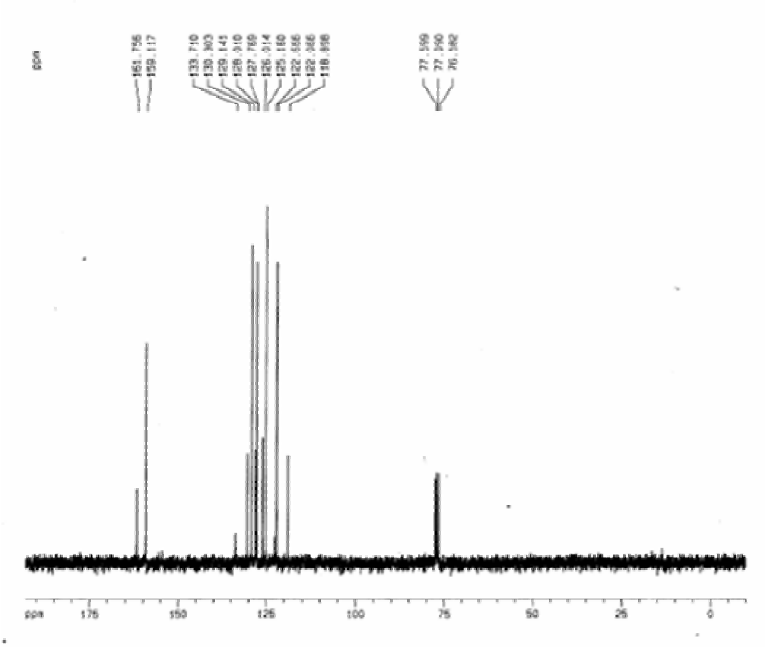

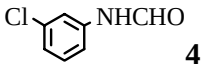

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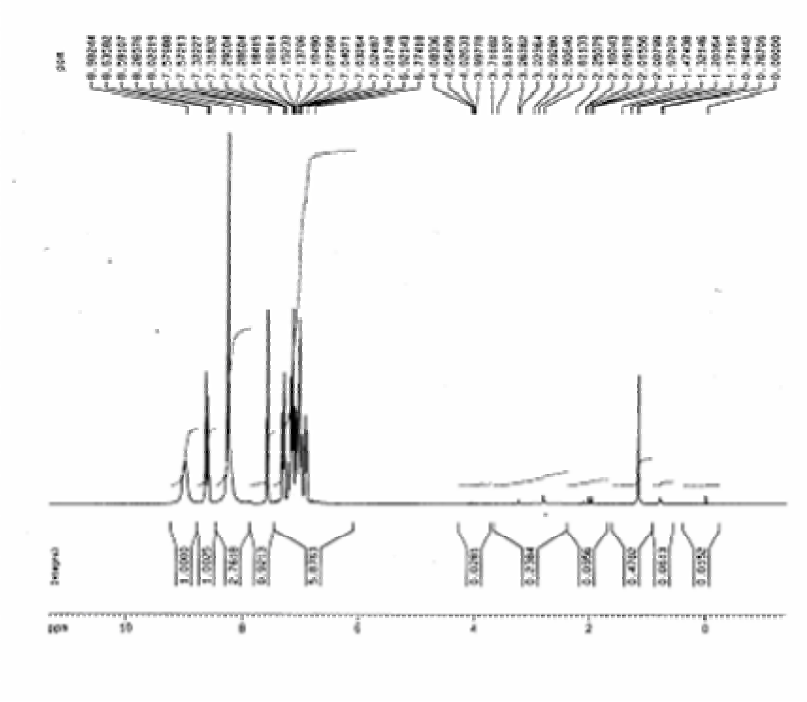

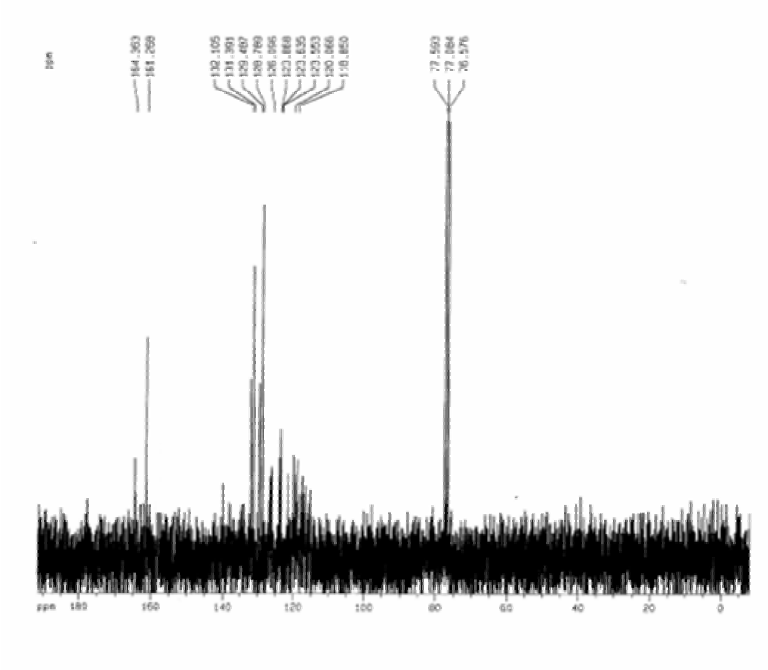

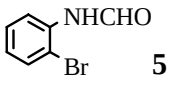

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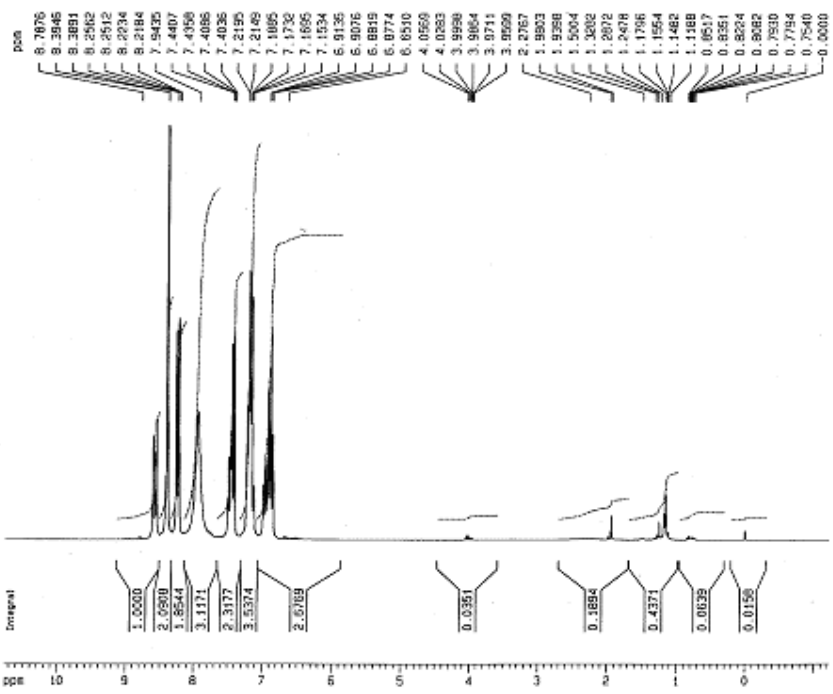

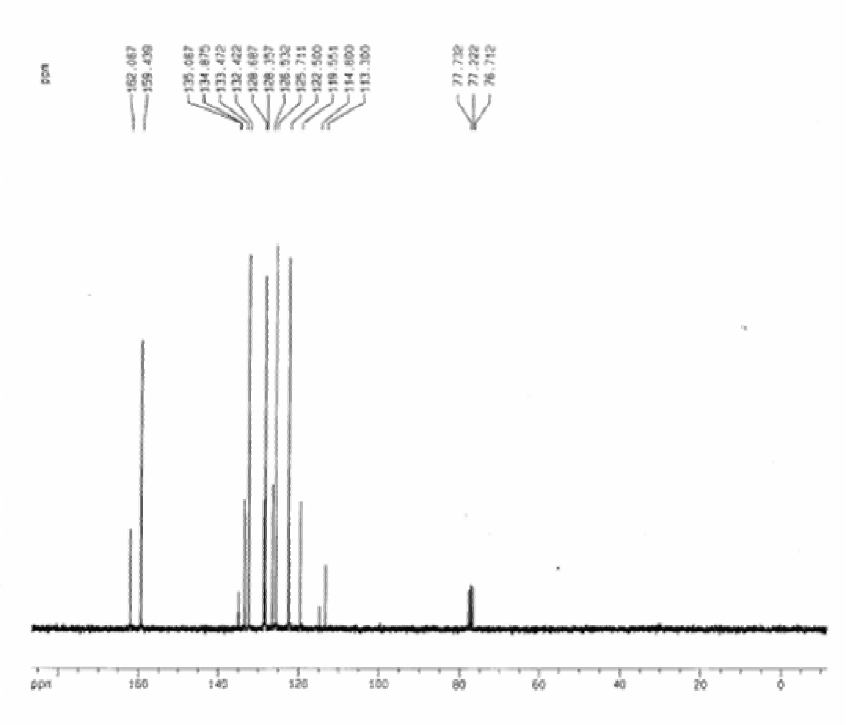

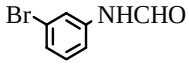

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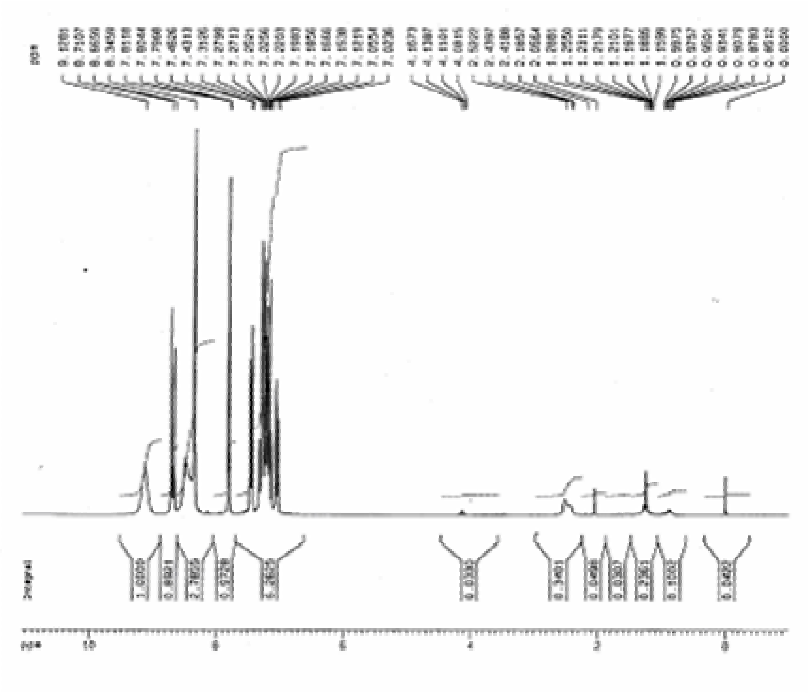

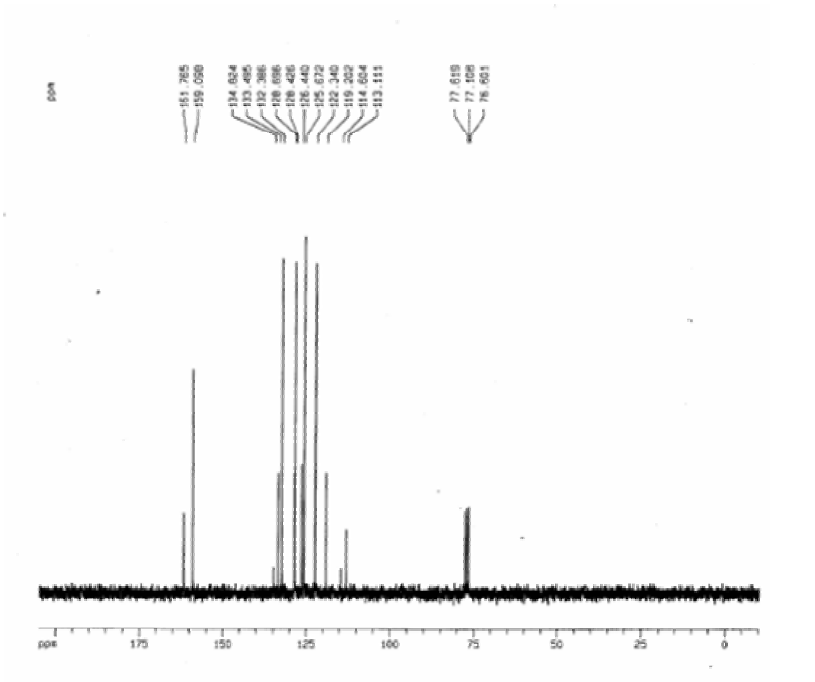

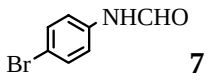

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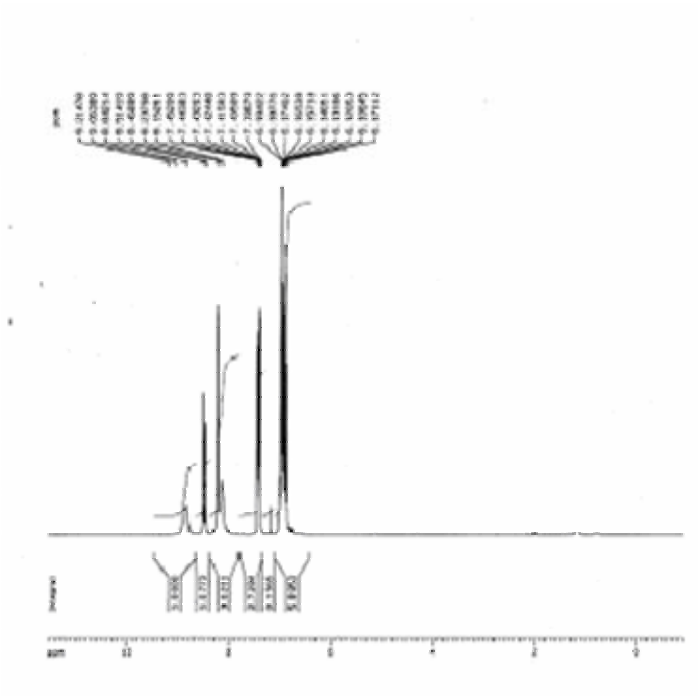

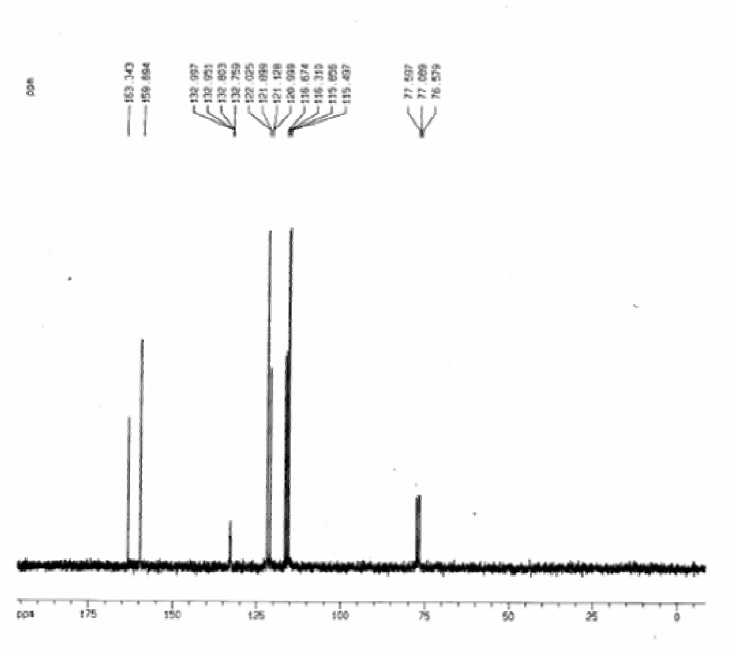

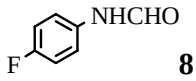

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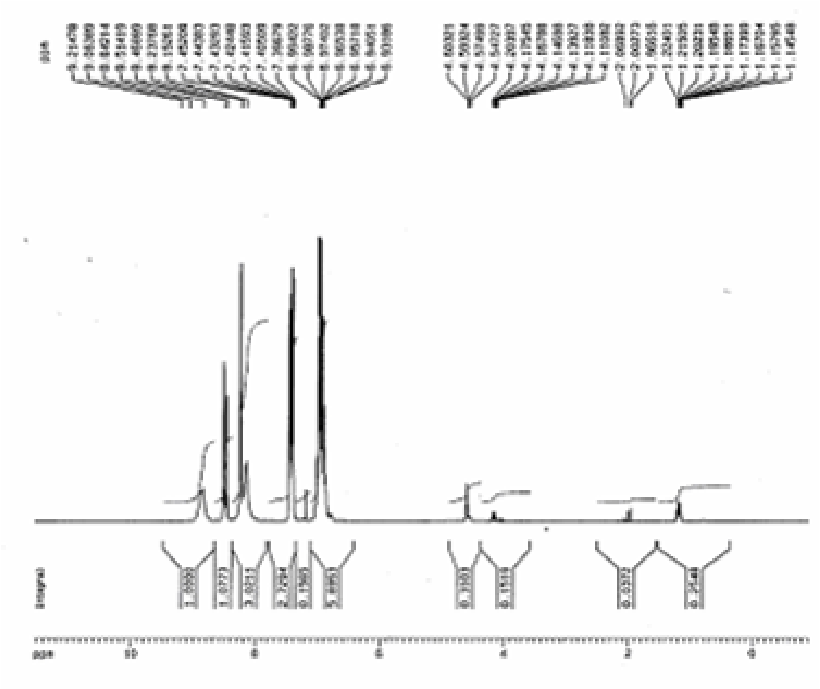

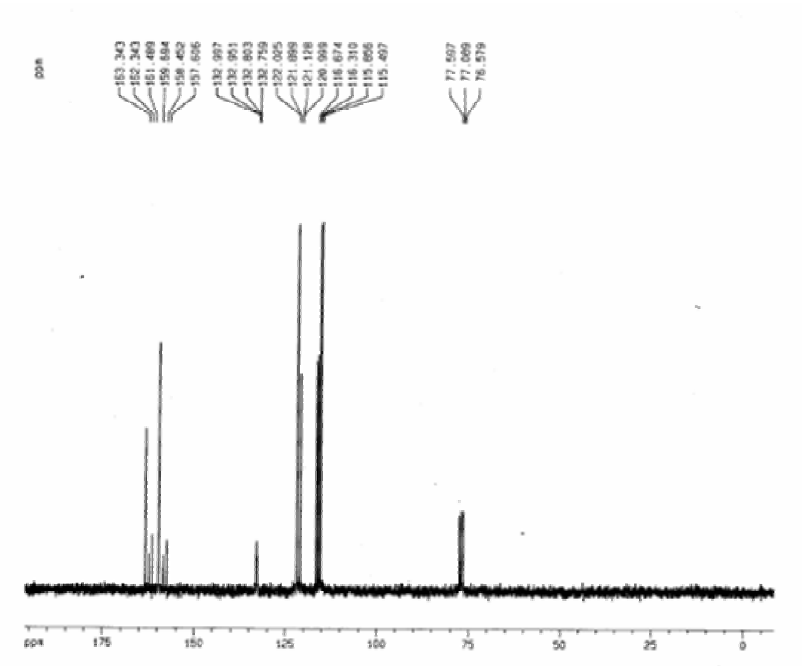

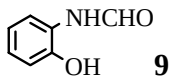

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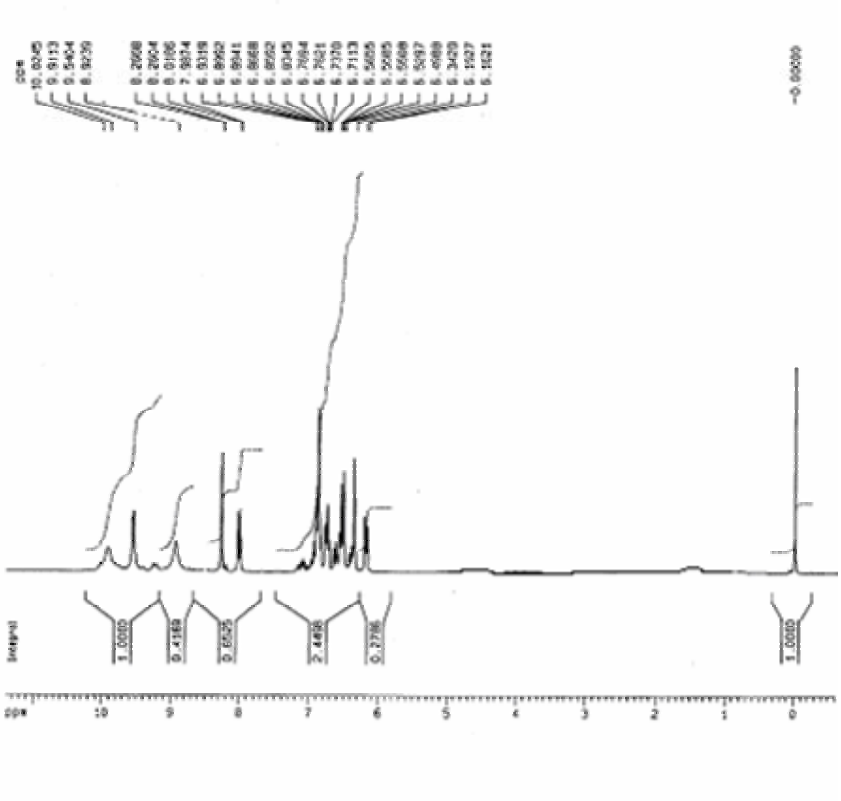

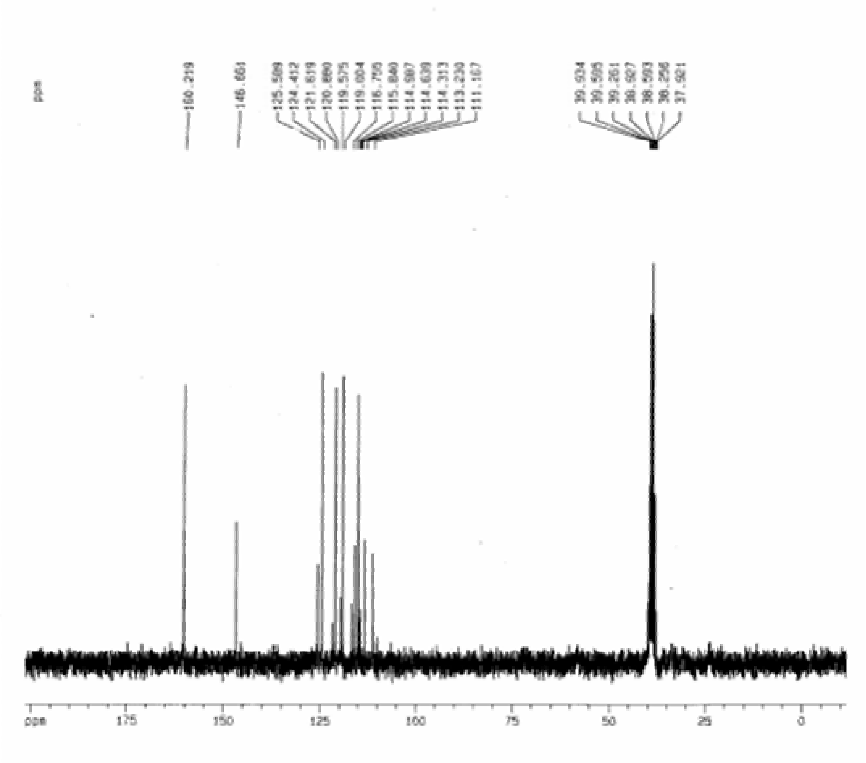

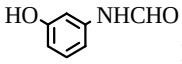

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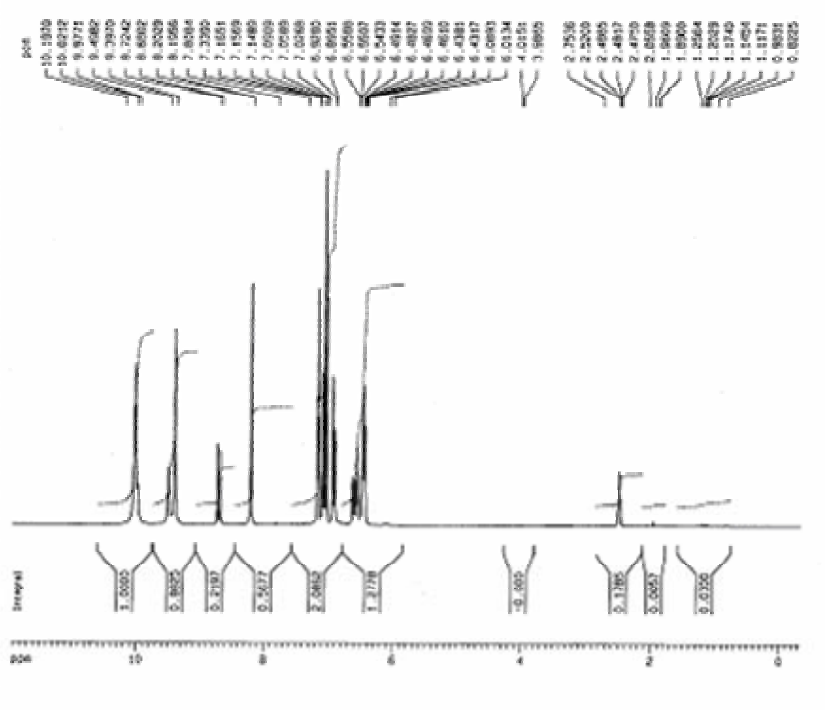

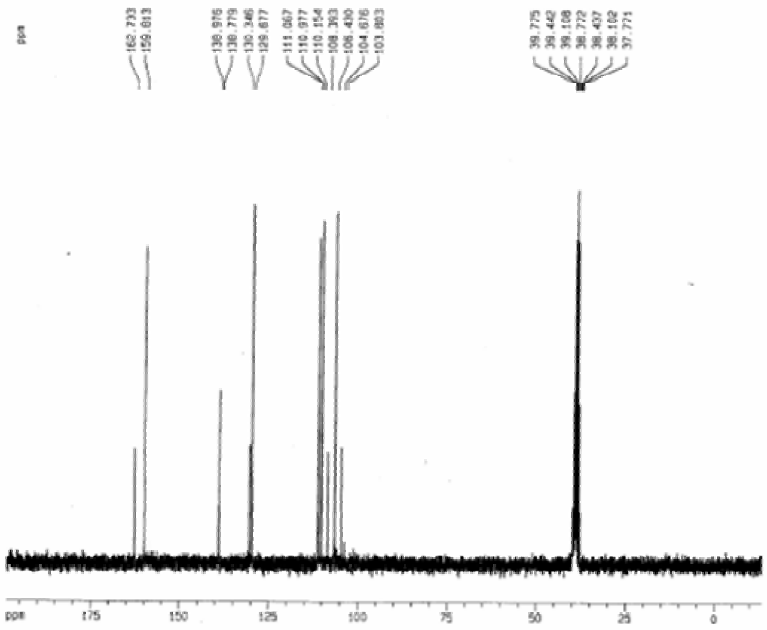

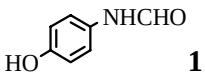

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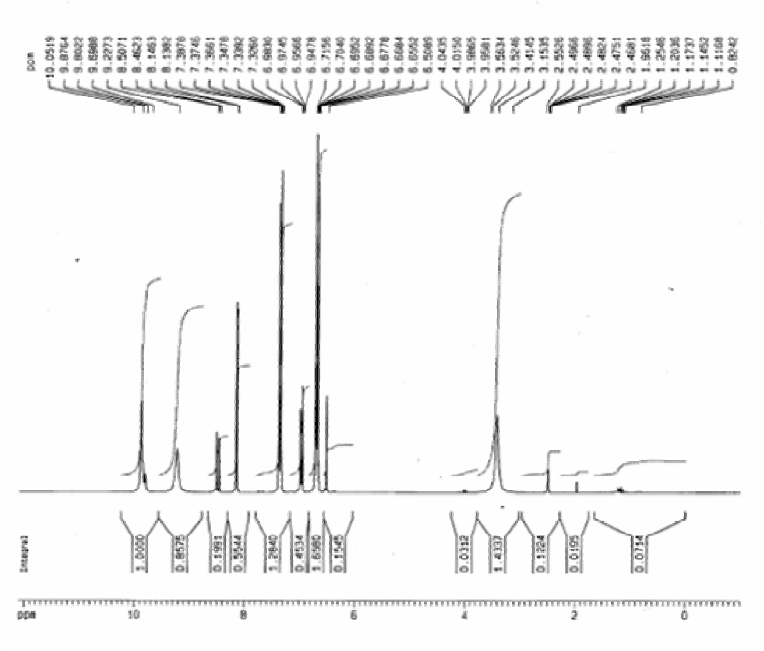

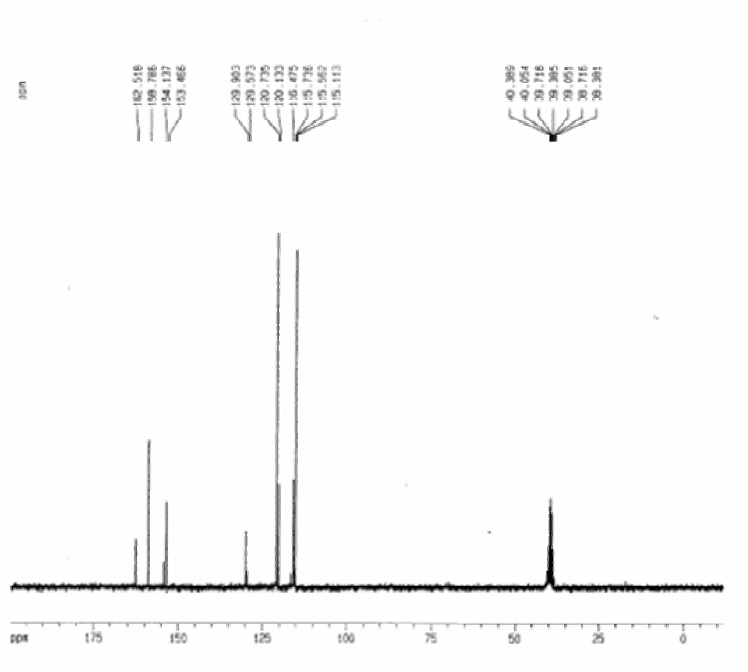

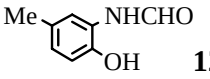

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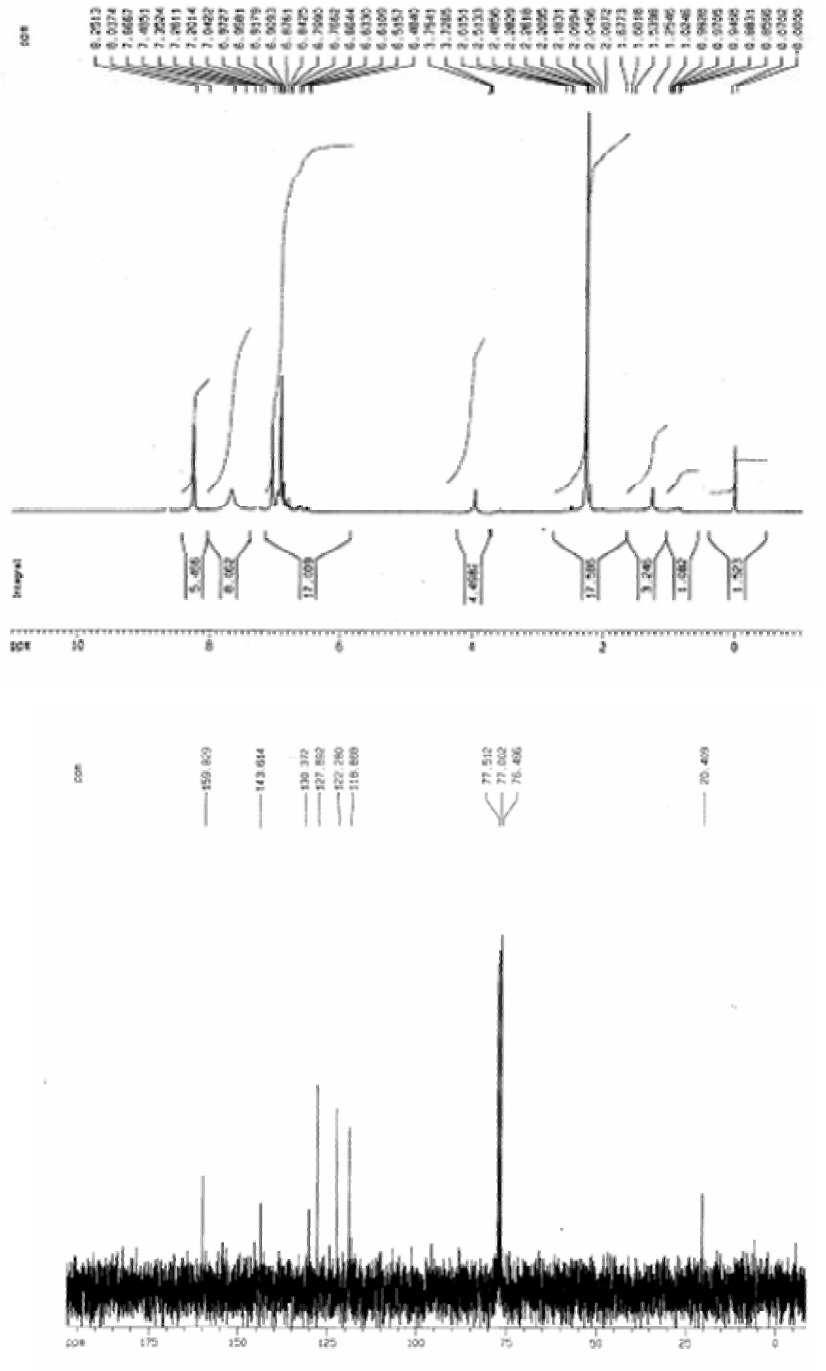

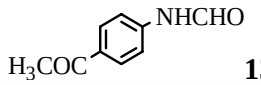

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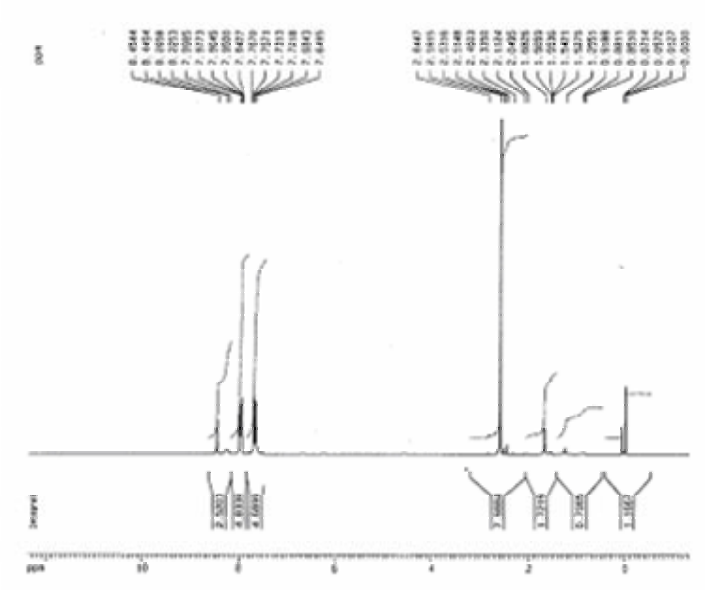

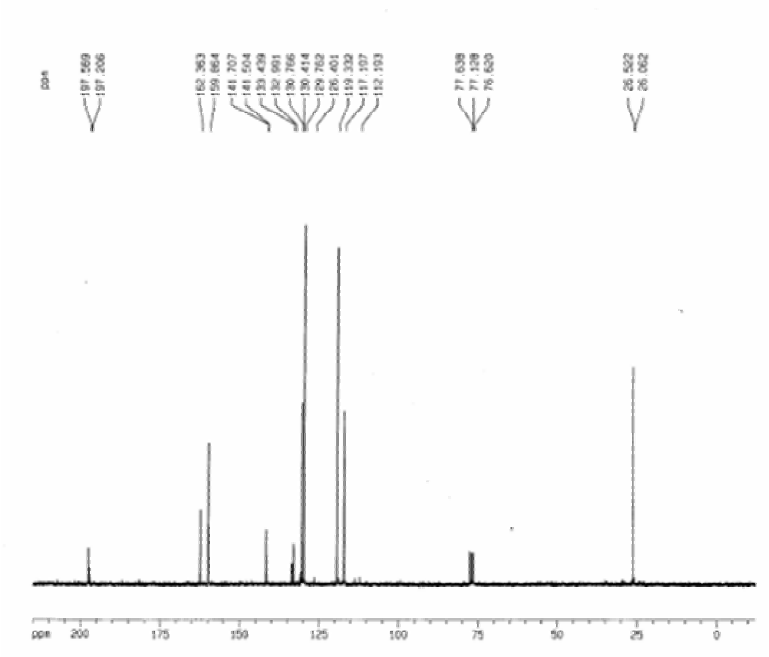

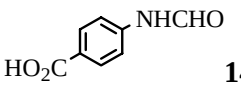

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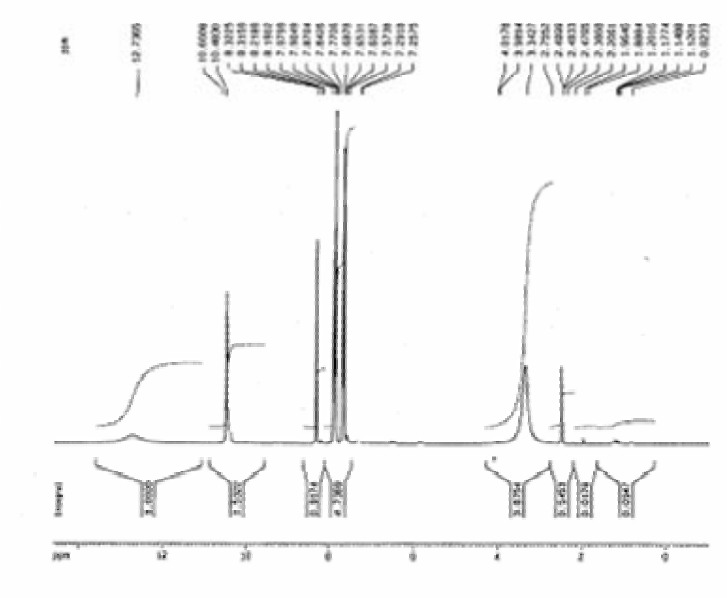

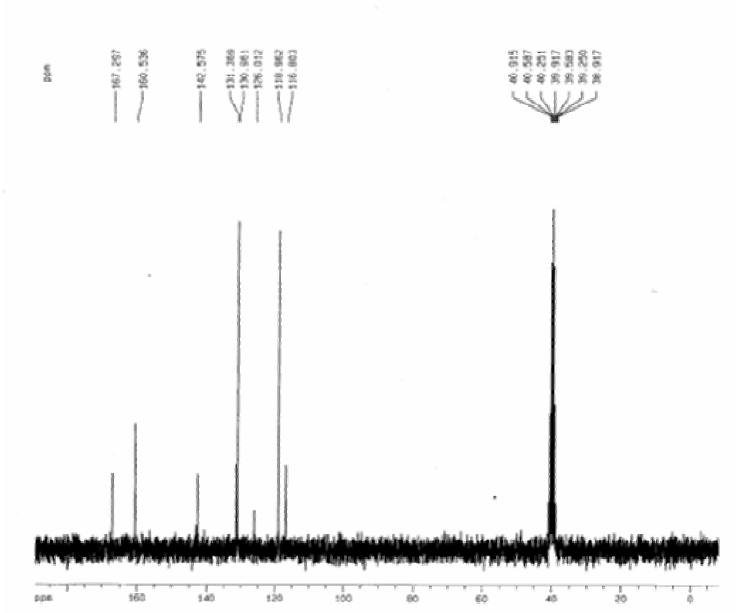

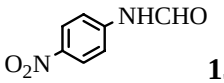

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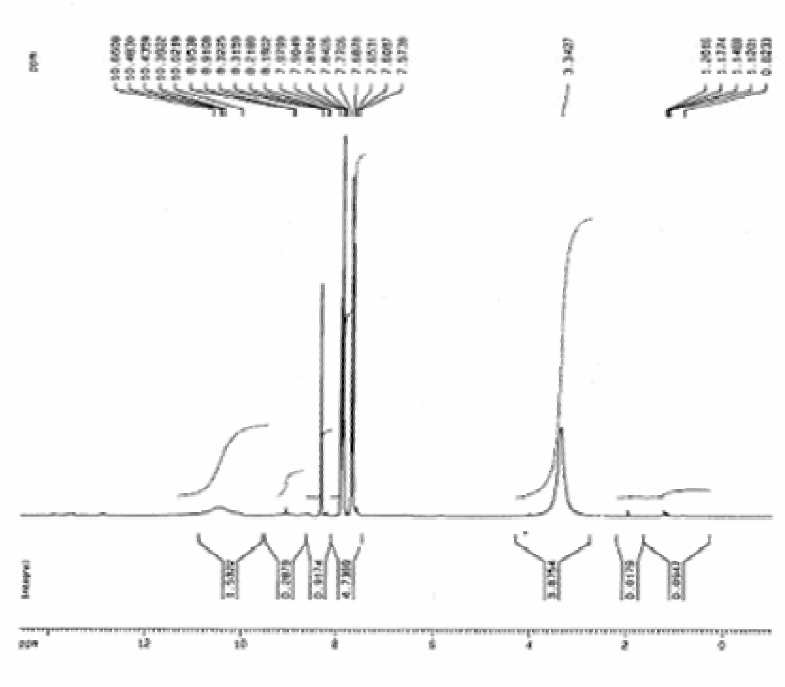

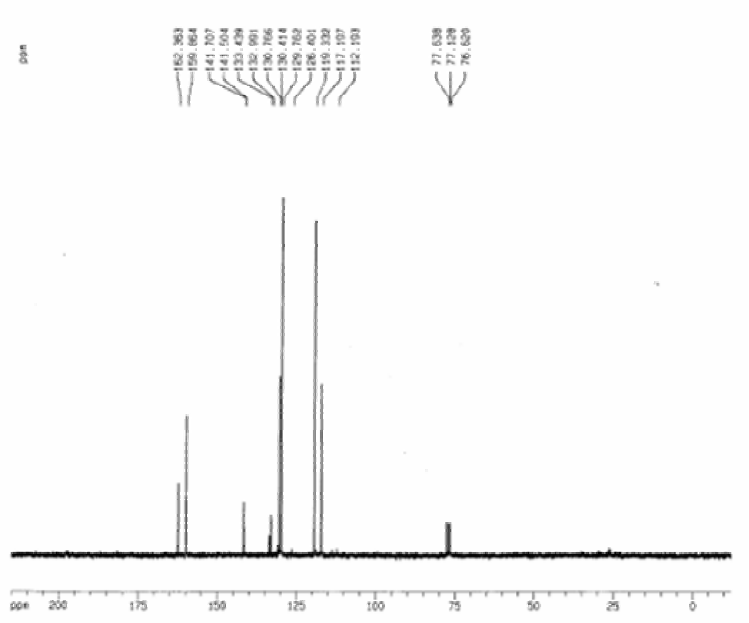

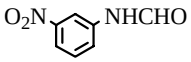

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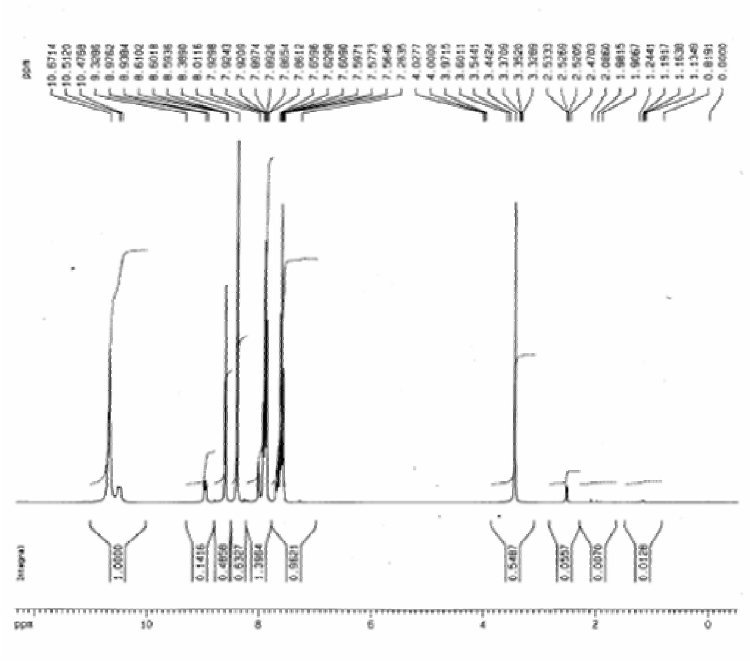

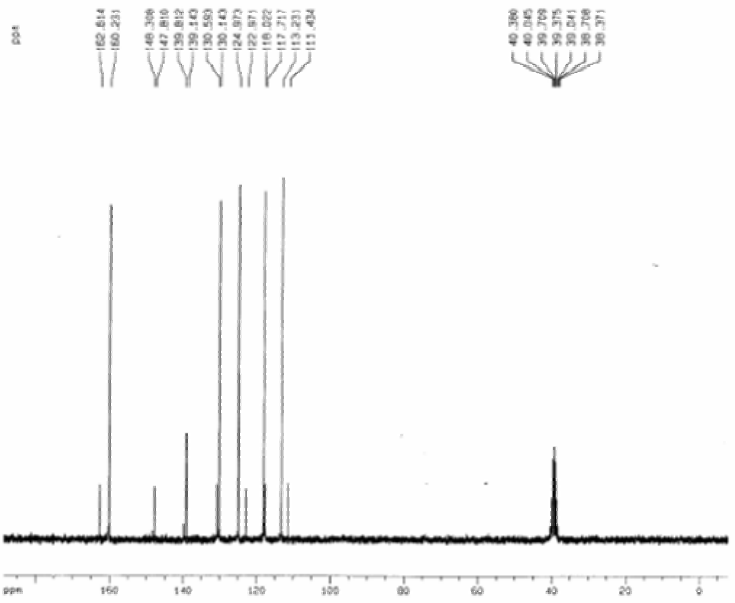

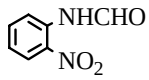

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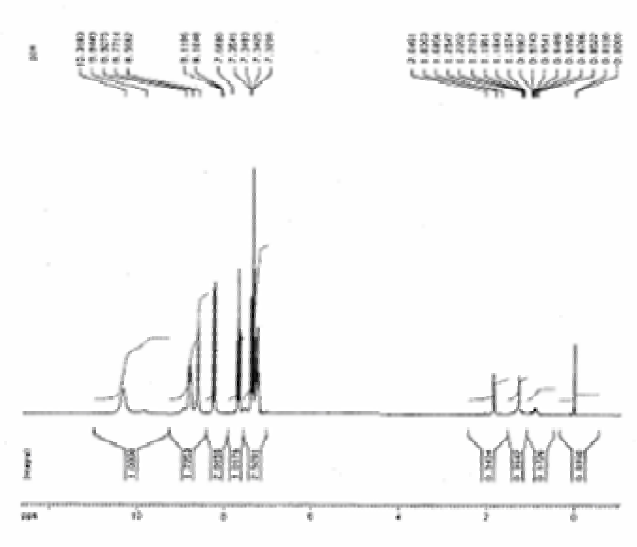

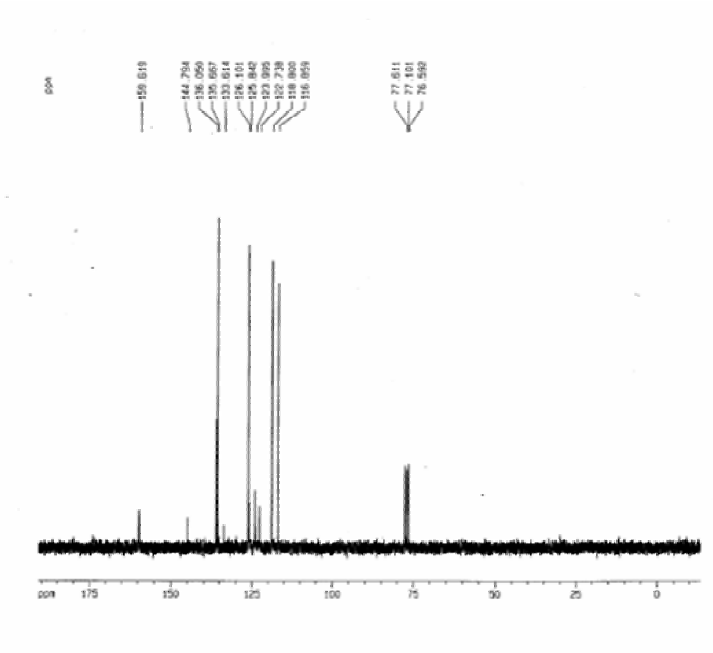

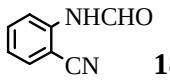

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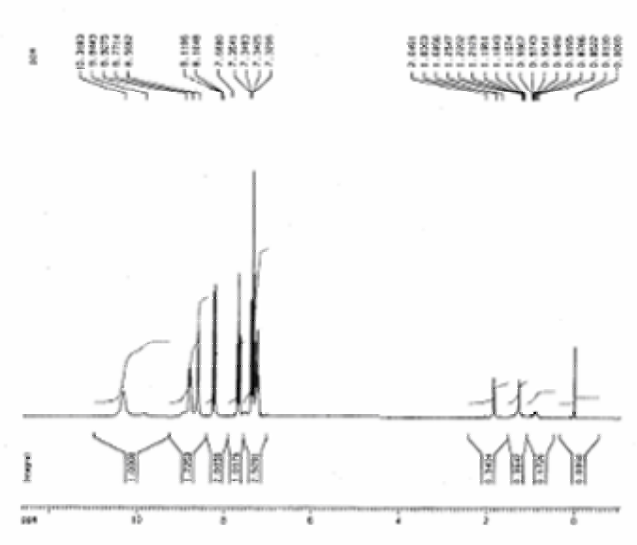

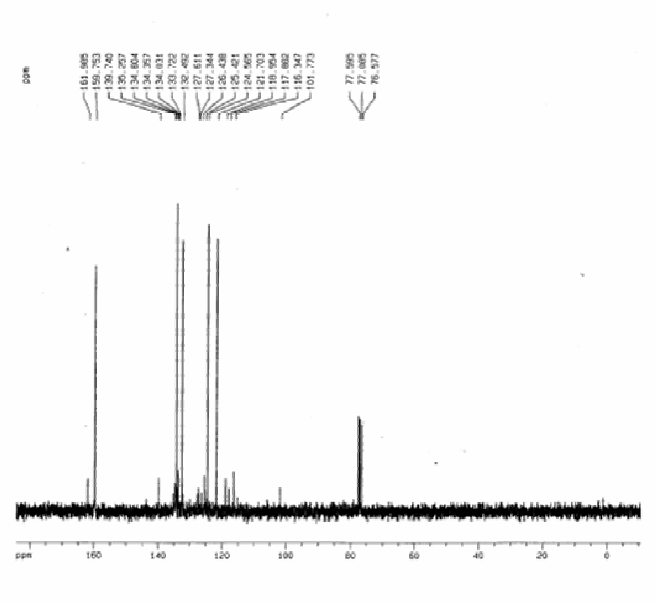

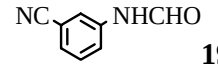

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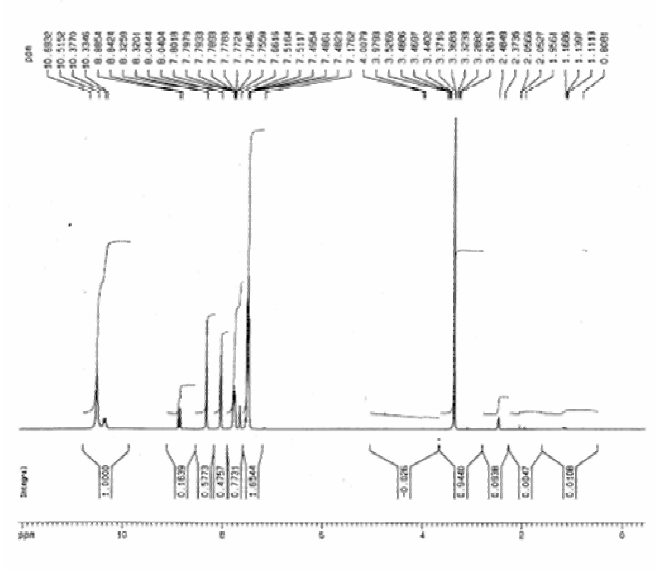

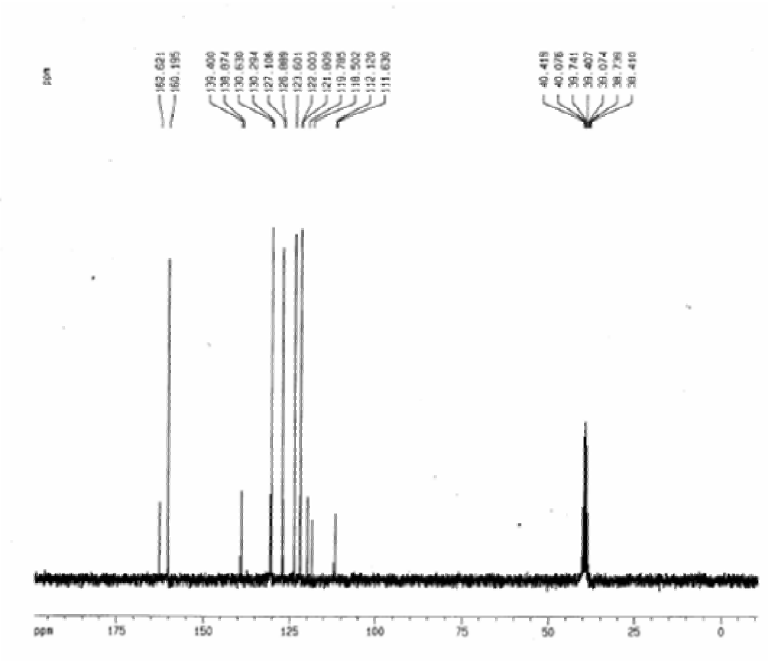

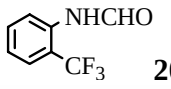

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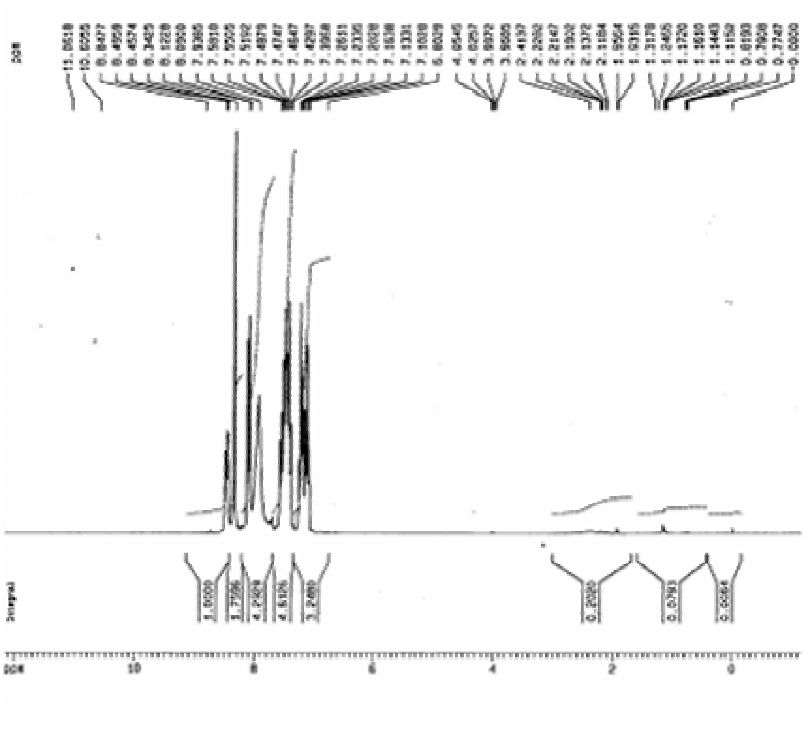

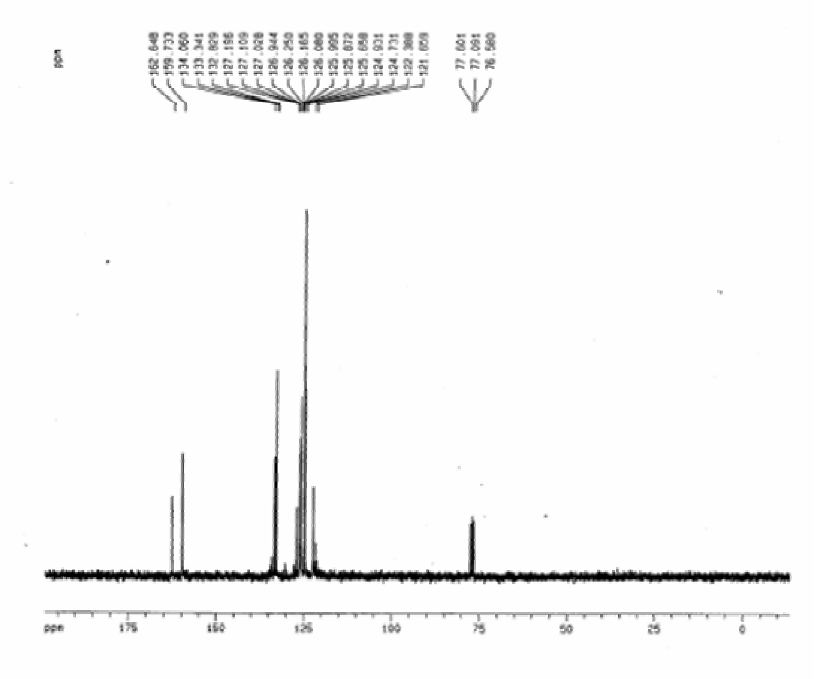

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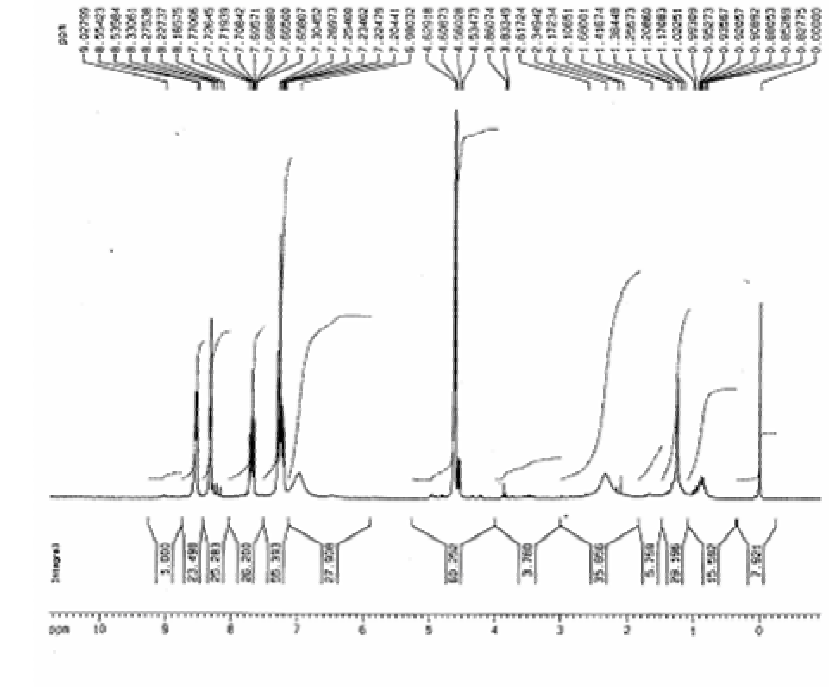

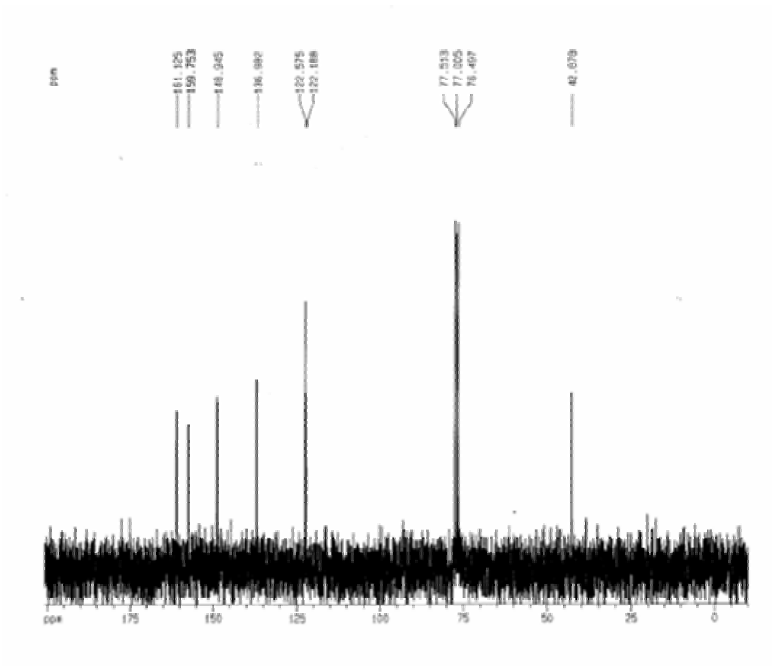

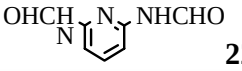

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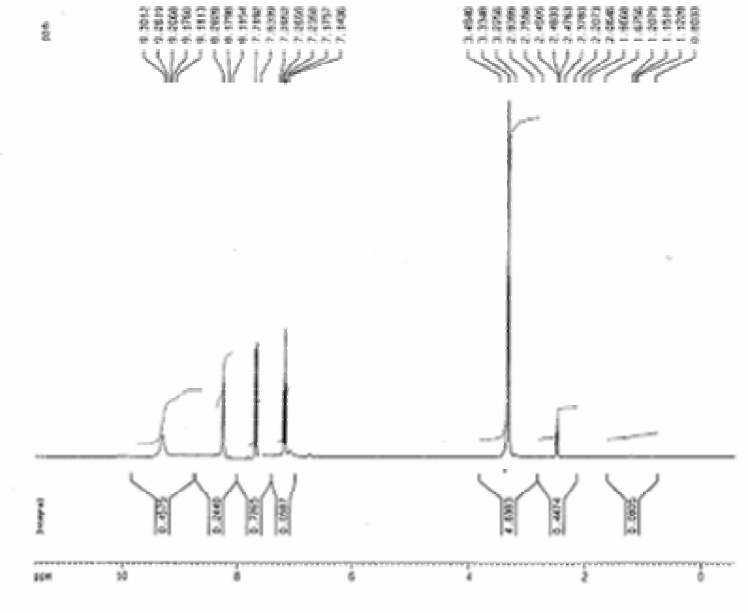
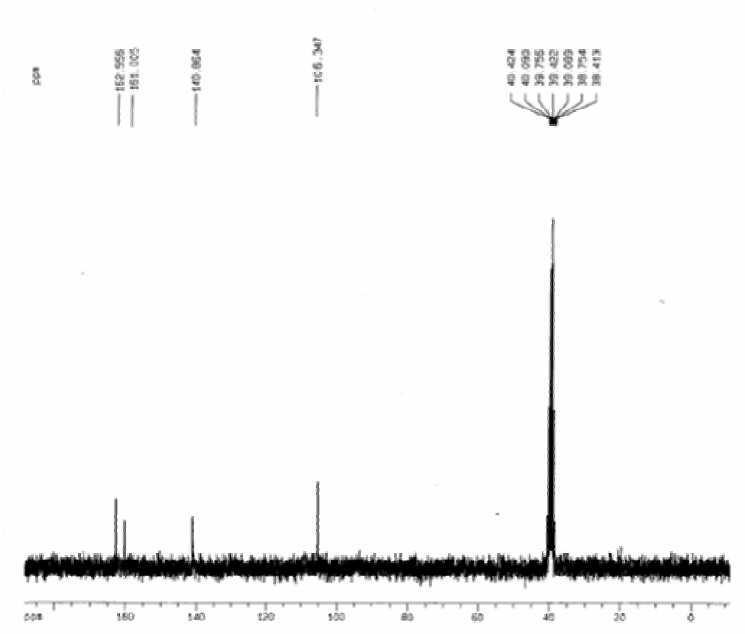
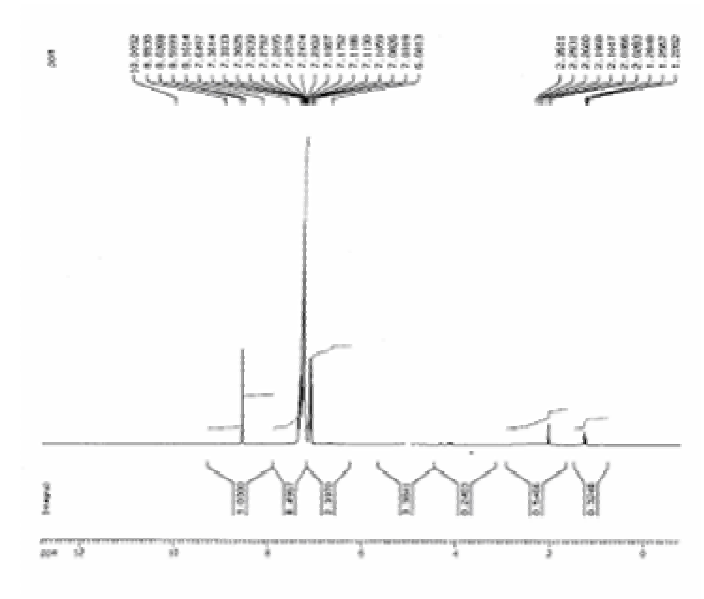
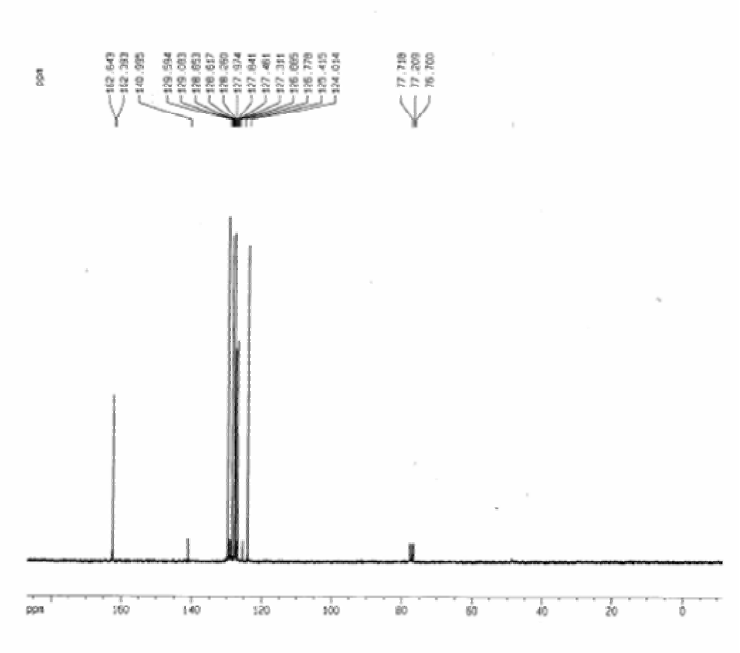




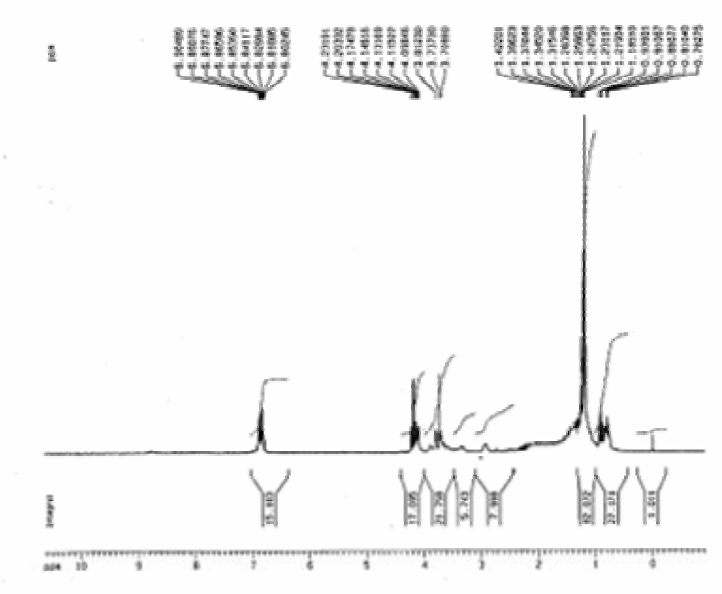
PhN(CHO)Ph

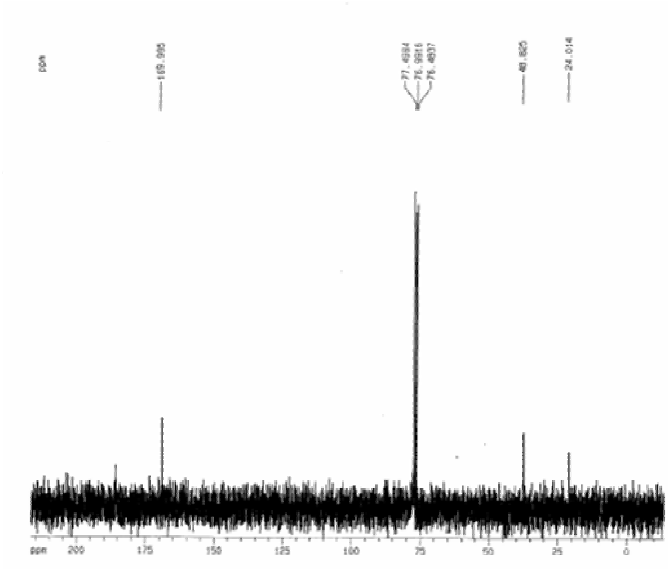
23



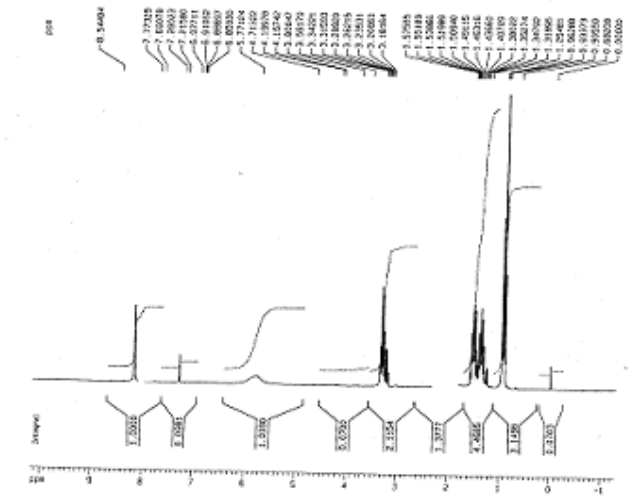


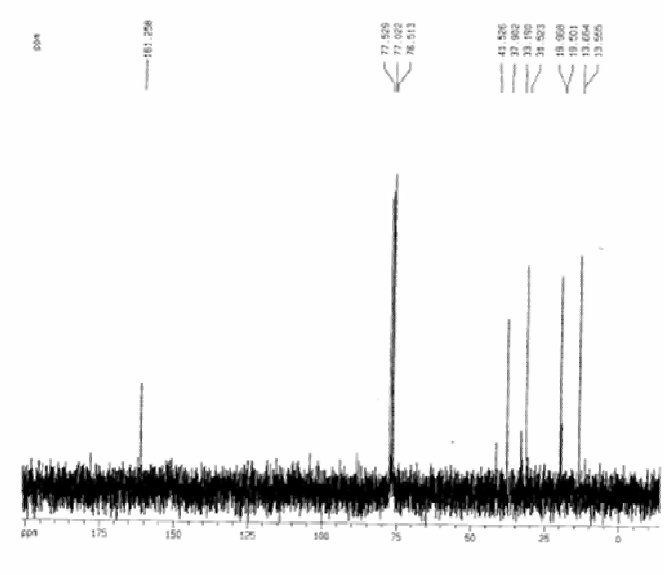
$(CH_3)_2CHN(CHO)CH(CH_3)_2$
24





$CH_3CH_2CH_2CH_2NHCHO$
25





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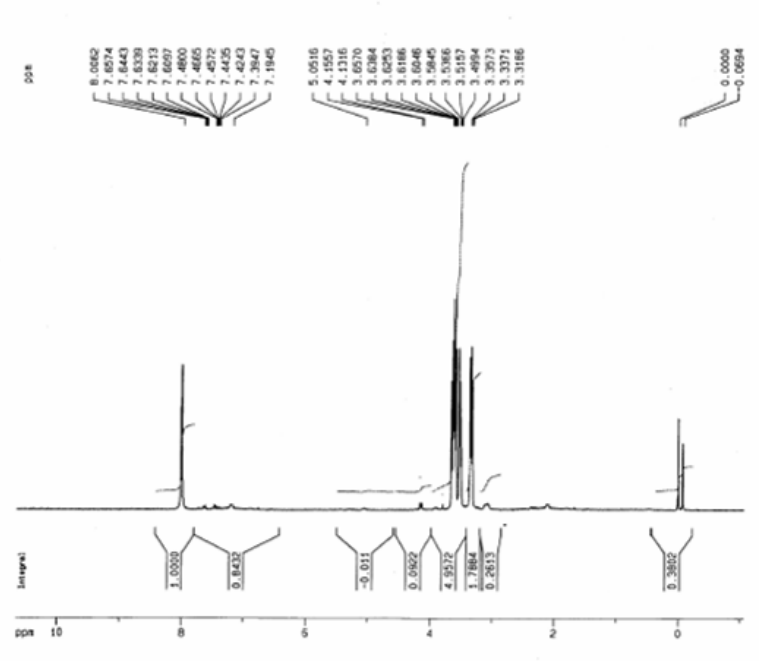
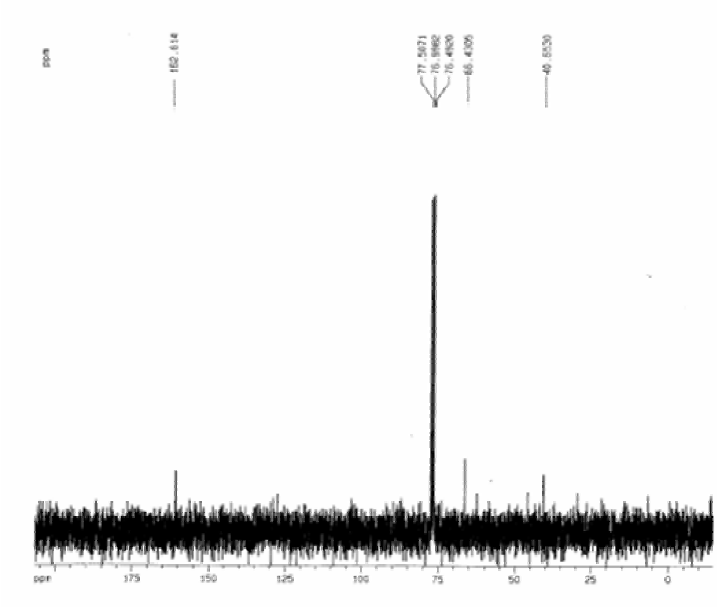
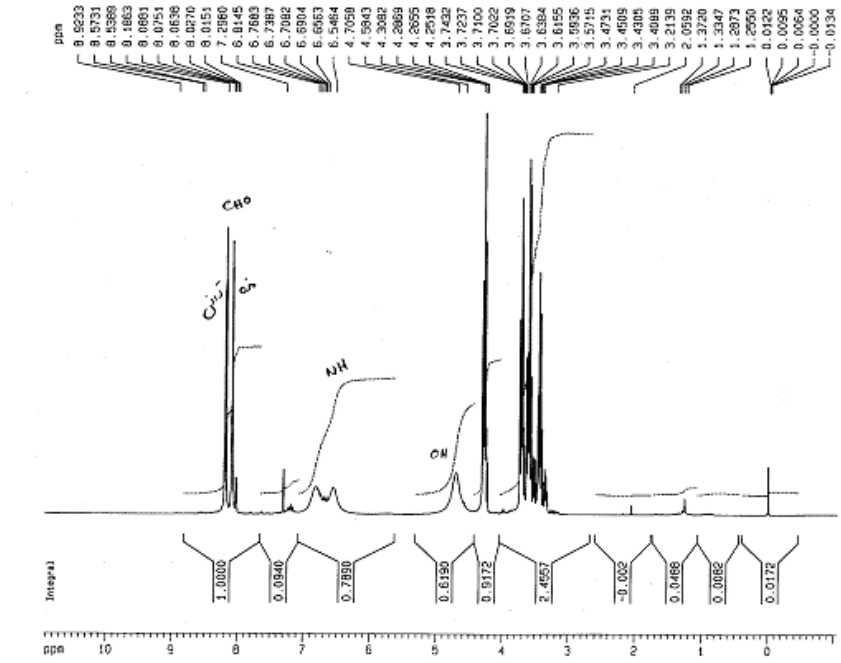
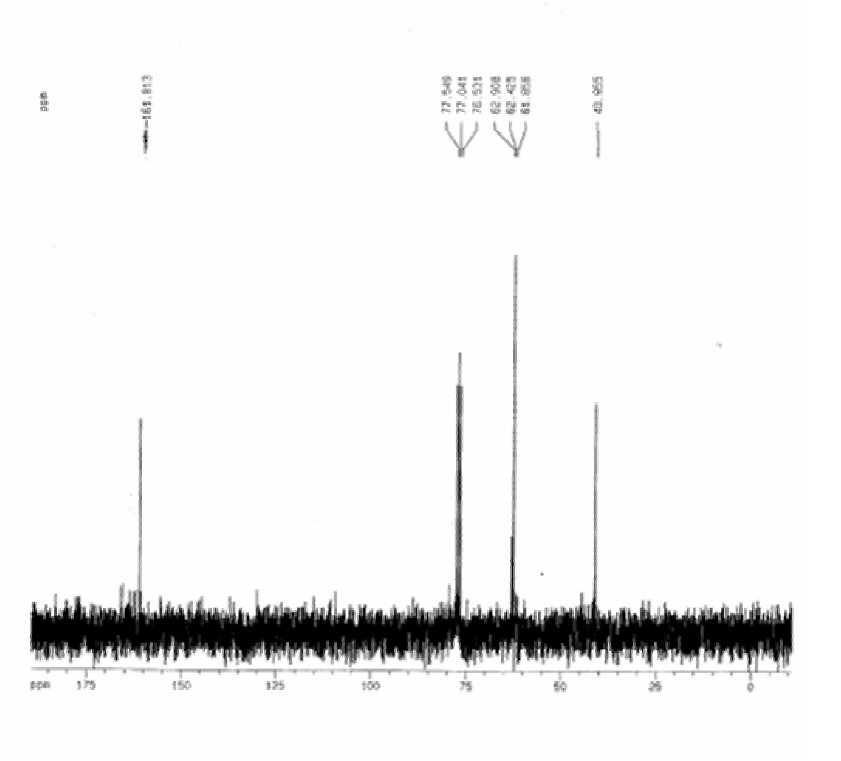
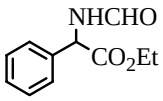




$HOCH_2CH_2NHCHO$
27







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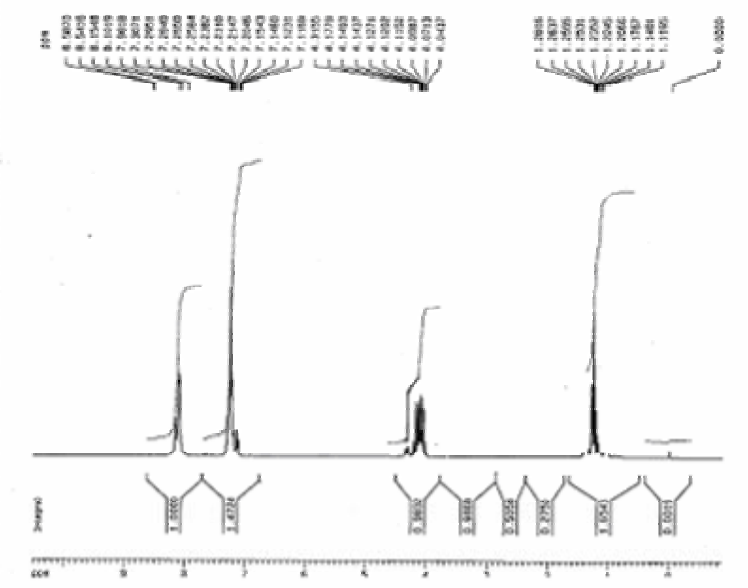

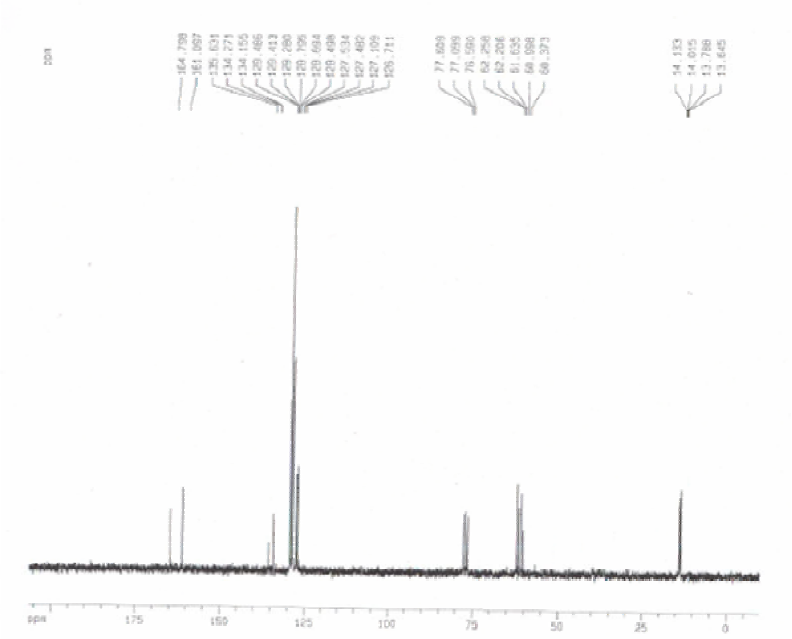

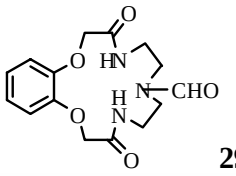

29